GLOBAL, MULTIYEAR VARIATIONS OF OPTICAL THICKNESS WITH TEMPERATURE IN LOW AND CIRRUS CLOUDS.

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ABSTRACT

The International Satellite Cloud Climatology Project (ISCCP) dataset is used to correlate variations of cloud optical thickness and cloud temperature in today's atmosphere. The analysis focuses on low and cirrus clouds. Cold low clouds show increases in cloud optical thickness with temperature consistent with adiabatic behavior, while warm low clouds primarily show decreases in cloud optical thickness with temperature. An exception are subtropical low clouds which show a tendency for increases in optical thickness with temperature, particularly during El Nino years. High and middle latitude cirrus clouds show increases in optical thickness with temperature. In subtropical and tropical latitudes, cirrus cloud optical thicknesses show a complicated behavior that could be related to changes in the dynamical regime in which the clouds are formed.

1. INTRODUCTION

Systematic changes in the optical properties of clouds can result in strong feedbacks on climate change. Both the magnitude and sign of those feedbacks, however, vary widely in climate simulations depending on the parameterization of cloud processes employed in each climate model (e.g. Roeckner 1988, Mitchell et al.

1989, Le Treut and Li, 1991). Our inability to determine cloud optical property feedbacks comes from a lack of understanding of the large scale atmospheric processes that control cloud water, compounded by our poor knowledge of the large scale variations of cloud optical thickness. An analysis of one year of satellite observations over the Northern Hemisphere subtropics and midlatitudes (Tselioudis et al. 1992, hereafter referred to as TRR92) found systematic correlations between fluctuations of the optical thickness and the temperature of low clouds. The correlations are consistent as temperature varies with latitude, season, and day: in cold cloud ensembles low cloud optical thickness increases with temperature but in warm cloud ensembles it decreases with temperature. The results of TRR92 are extended in this study to include clouds in all climate regimes (except polar) of both hemispheres. Furthermore, the analysis is performed for eight years of data and the interannual variations of the optical thickness-temperature relation are examined. Finally, systematic changes in the optical thickness of cirrus clouds are correlated to changes in their temperature, and the differences between the temperature behavior of low and cirrus clouds are discussed.

2. THE DATASET

The dataset analyzed in this study is produced by the International Satellite Cloud Climatology Project (ISCCP) (Rossow and Schiffer 1991). The data will cover the period from July 1983 to June 1995; eight years are already completed. The dataset contains detailed information on the distribution of cloud radiative properties and their diurnal and seasonal variations, as well as information on the vertical distribution of temperature and humidity in the troposphere. The data are based on observations from the suite of operational weather satellites and are reported every three hours at 250 km resolution with seven levels in the vertical. For each map grid-box and pressure level, the number of cloudy pixels that belong to each of five optical thickness categories is given. Figure 1 shows the optical thickness categories and the vertical resolution of the cloud top pressures, together with the radiometric definition of the low and cirrus cloud types that are examined in this study.

3. RESULTS

Eight years of data (July 1983-June 1991) are analyzed by correlating changes in the optical thickness of low and cirrus clouds to changes in cloud temperature. To do that, the logarithmic derivative of cloud optical thickness with cloud temperature (dlnTAU/dT)[1] is calculated for each month and latitude, separately for clouds over land and ocean. Monthly mean values are used to derive seasonal means for each year, and then the seasonal dlnTAU/dT values for the eight years in the dataset are averaged and plotted against latitude.

Figure 2 shows the latitudinal distribution of dlnTAU/dT in the four seasons for low clouds over land (Fig. 2a) and over ocean (Fig. 2b). Positive dlnTAU/dT values are observed only in Northern Hemisphere winter continental clouds (Fig. 2a) and in high latitude maritime clouds (Fig. 2b), indicating that in the colder cloud ensembles (mean ensemble temperature less than -10^o C) low cloud optical thickness increases with temperature. In all warmer cloud ensembles (mean ensemble temperature greater than 0^o C) over land and ocean, however, the values of dlnTAU/dT are negative indicating decreases in low cloud optical thickness with temperature. The results in Figure 2 reaffirm the conclusions of the one year, Northern-Hemisphere-only analysis of TRR92. The positive values of dlnTAU/dT in cold continental clouds average around 0.04 and are in the range of the

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[1] The analysis procedure isolates only the systematic variation of optical thickness with temperature, but optical thickness can vary with other parameters. For more details on the analysis procedure refer to TRR92.

theoretically predicted rate of change of the adiabatic cloud liquid water content with temperature (Betts and Harshvardhan 1987). This suggests that optical thickness changes in colder clouds are dominated by changes in the adiabatic liquid water content. In warmer cloud ensembles over both land and ocean the optical thickness of low clouds decreases with temperature and dlnTAU/dT ranges between -0.05 and -0.15 depending on latitude and location of the cloud over land or ocean. This decrease is present in most warm cloud ensembles independent of changes in the dynamic regime in which the clouds are embedded (Tselioudis 1992) and could be due to non-adiabatic processes that deplete cloud water with increasing efficiency as temperature increases. In TRR92 precipitation is suggested as the prime candidate for such a process.

The interannual variability of monthly dlnTAU/dT values is represented by the month of January in Figure 3, where the curves for January 1986 and January 1987 (the two main El Nino years in the dataset) are plotted together with the range of change of the dlnTAU/dT values for the other six Januarys in the dataset. In clouds over land (Figure 3a), the high Northern latitudes show high positive dlnTAU/dT values in all eight years of the analysis, while the low latitudes show dlnTAU/dT values that are predominately negative. The one major exception are subtropical Northern Hemisphere clouds, which, particularly in 1986 and 1987, show positive dlnTAU/dT values. In clouds over ocean (Figure 3b) the scatter between the eight curves is fairly small and the main features of positive or near-zero values at the higher latitudes and negative values in the lower latitudes are present in all eight years. The exception again are Northern Hemisphere subtropical clouds, where in January 1986 and January 1987 the dlnTAU/dT values are positive and above the range of the other six Januarys. In maritime clouds and, to a lesser degree, in continental clouds, the two El Nino years show generally higher values of dlnTAU/dT than the rest of the years in the dataset.

The temperature behavior of cirrus cloud optical thickness is shown in Figure 4, where the latitudinal distribution of dlnTAU/dT in the four seasons is plotted for cirrus clouds over land (Fig. 4a) and over ocean (Fig. 4b). In the middle and higher latitudes of both Hemispheres, cirrus clouds in all seasons over both land and ocean show positive dlnTAU/dT values. These values average around 0.08, and are within the range of the ones that Platt and Harshvardhan (1989) calculated using aircraft measurements of cloud water content and lidar observations of cloud vertical extent. In the subtropical and tropical regions, however, the value of dlnTAU/dT for cirrus clouds exhibits features with strong latitudinal and seasonal dependence. Cirrus clouds over land show a strong negative peak in Northern Hemisphere winter subtropical clouds and weaker negative peaks in Southern Hemisphere fall and winter subtropical clouds. The N.H. negative peak in the winter subtropics coincides with strong positive peaks in summer and fall clouds. Cirrus clouds over ocean show negative peaks in subtropical clouds during the winter and spring periods of each hemisphere, and a pair of contrasting positive and negative peaks in the Southern and Northern tropical regions respectively.

4. DISCUSSION

The latitudinal and seasonal distributions of dlnTAU/dT presented in Figures 2 and 4 reveal one common feature but also significant differences in the temperature behavior of low and cirrus clouds. The common feature is related to the overall tendency for positive dlnTAU/dT values in the colder low cloud ensembles and in the high latitude cirrus cloud ensembles. Such values are consistent with increases in the adiabatic cloud water content with temperature. In the warmer cloud ensembles, however, low clouds show almost exclusively negative dlnTAU/dT values indicating a predominant influence of non-adiabatic processes on the cloud water. Low latitude cirrus clouds exhibit a more complicated behavior that points to a probable dynamic control on the temperature change of cloud optical thickness. The seasonally contrasting peaks in the Northern Hemisphere subtropics and the positive peak in the Southern Hemisphere tropics (Fig. 4) could be related to the location of the clouds in the upward or downward branches of the Hadley cell, although a comparison to vertical velocities does not show a simple relationship. Some indication of dynamic influence is also present in the low cloud results, where the warm subtropical clouds, particularly in EL Nino years, change to positive dlnTAU/dT values. All these issues require further investigation by combining more detailed radiative, dynamical and cloud microphysical datasets, as well as large scale cloud models based on physical principles.

Optical thickness changes of the same sign in low and cirrus clouds would tend to produce climate feedbacks of opposite signs. The results presented here indicate that the net change in a warmer climate will depend on more complex changes related to both thermodynamic and dynamic conditions, with the relative importance of the two shifting according to cloud type and climate regime. All this clearly suggests that the question of cloud optical property feedbacks on climate is very complex and can be resolved only if we understand the large scale atmospheric processes that influence the optical thickness of clouds. Satellite observations can be used as a very useful tool to test and constrain any new physical treatment of cloud optical properties in climate models.

REFERENCES

Betts, A. K., and Harshvardhan, 1987: Thermodynamic constraint on the cloud liquid water feedback in climate models. *J. Geophys. Res.*, **92**, 8483-8485.

Le Treut, H., and Z-X. Li, 1991: Sensitivity of an atmospheric general circulation model to prescribed SST changes: Feedback effects associated with the simulation of cloud optical properties. *Climate Dyn.*, **5**, 175-187.

Mitchell, J. F. B., C. A. Senior, and W. J. Ingram, 1989: CO2 and climate: A missing feedback? *Nature*, **34**, 132-134.

Platt, C. M. R., and Harshvardhan, 1988: Temperature dependence of cirrus extinction: Implications for climate change. *J. Geophys. Res.*, **93**, 11051-11058.

Roeckner, E., 1988: Negative or positive cloud optical depth feedback? *Nature*, **335**, 304.

Rossow, W. B., and R. A. Schiffer, 1991: ISCCP cloud data products. *Bull. Amer. Meteor. Soc.*, **72,** 2-20.

Tselioudis, G., W. B. Rossow, and D. Rind, 1992: Global patterns of cloud optical thickness variation with temperature. *J. Climate*, **5,** 1484-1495.

Tselioudis, G., 1992: Global patterns of cloud optical thickness variation with temperature. and the implications for climate change. Ph.D Thesis, Columbia University, 143pp.

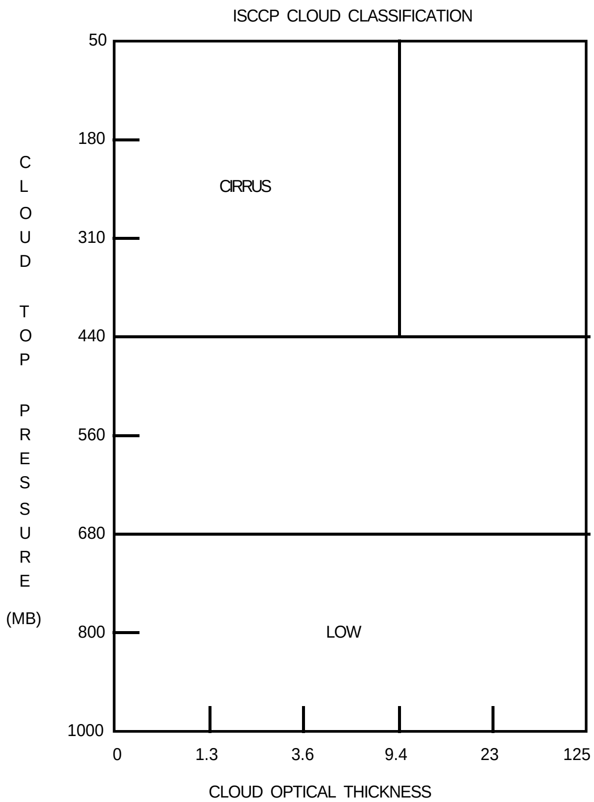
FIGURE CAPTIONS

Figure 1. Cloud optical thickness categories and cloud top pressure vertical resolution as reported in the ISCCP dataset, and radiometric definitions of the low and cirrus cloud types derived from the data.

Figure 2. Latitudinal distribution of dlnTAU/dT for a) low clouds over land and b) low clouds over ocean for the four seasons. The values plotted are averages over the eight seasons that are included in the July 1983-June 1991 time period.

Figure 3. Latitudinal distribution of dlnTAU/dT for January 1986 (solid line) and January 1987 (dashed line), and range of change of dlnTAU/dT for the other six Januarys in the time period (vertical bars), for a) clouds over land and b) clouds over ocean.

Figure 4. As in Figure 2, for a) cirrus clouds over land and b) cirrus clouds over ocean.


ISCCP CLOUD CLASSIFICATION
C
L
O
U
D

T
O
P

P
R
E
S
S
U
R
E

(MB)
50
180
310
440
560
680
800
1000
CIRRUS
LOW
0
1.3
3.6
9.4
23
125
CLOUD OPTICAL THICKNESS

Figure 1

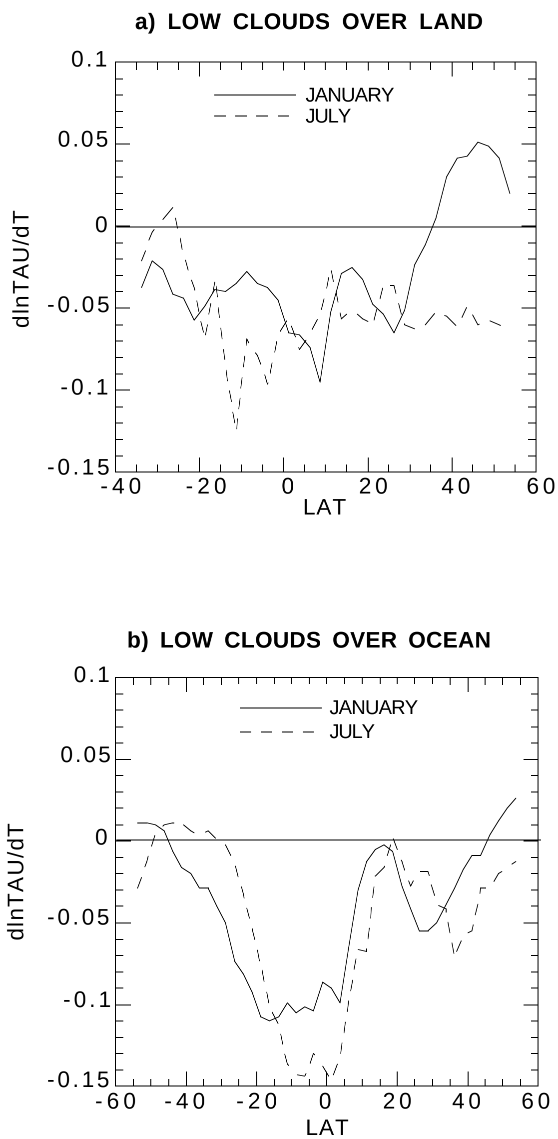

a) LOW CLOUDS OVER LAND
JANUARY
JULY
dlnTAU/dT
LAT
b) LOW CLOUDS OVER OCEAN
JANUARY
JULY
dlnTAU/dT
LAT

Figure 2

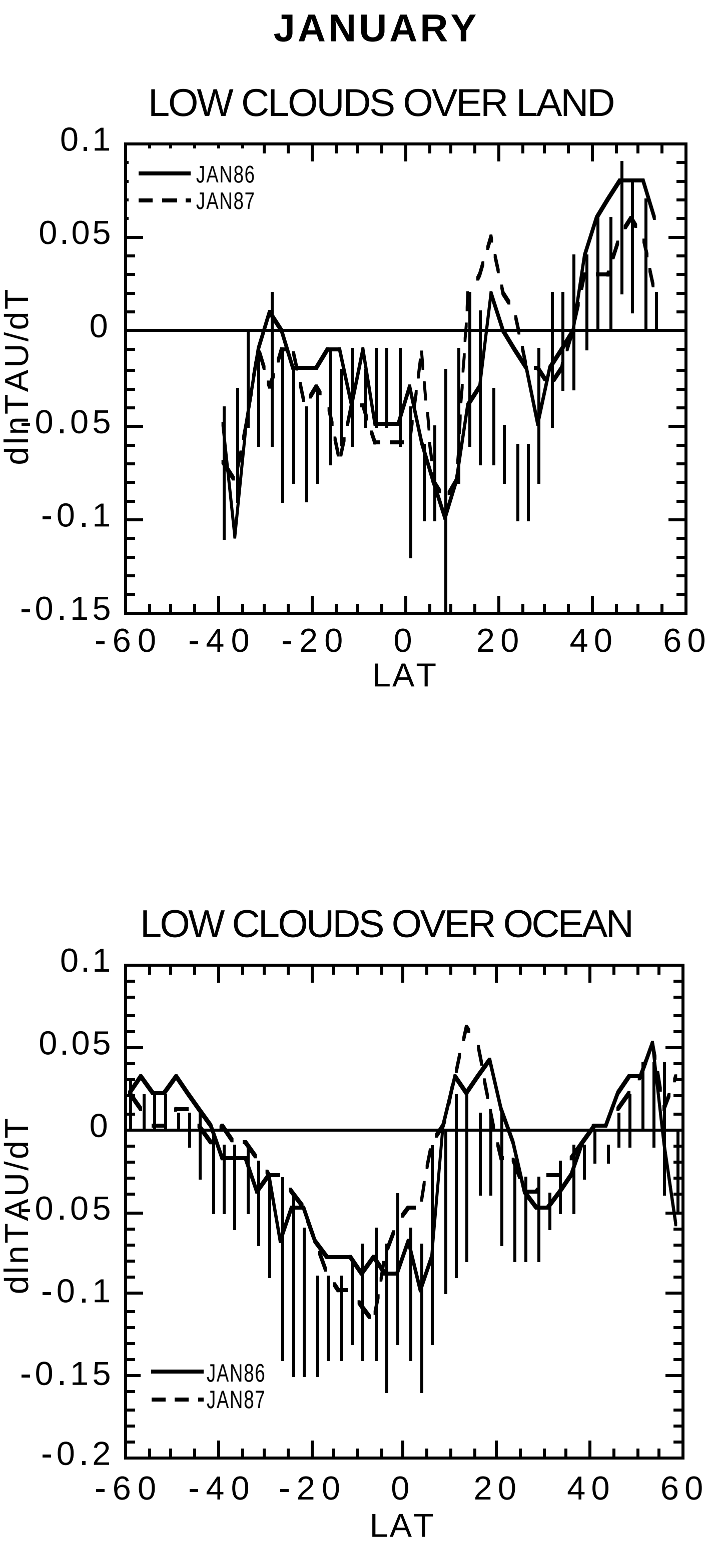

JANUARY
LOW CLOUDS OVER LAND
JAN86
JAN87
dlnTAU/dT
LAT
LOW CLOUDS OVER OCEAN
JAN86
JAN87
dlnTAU/dT
LAT

Figure 3

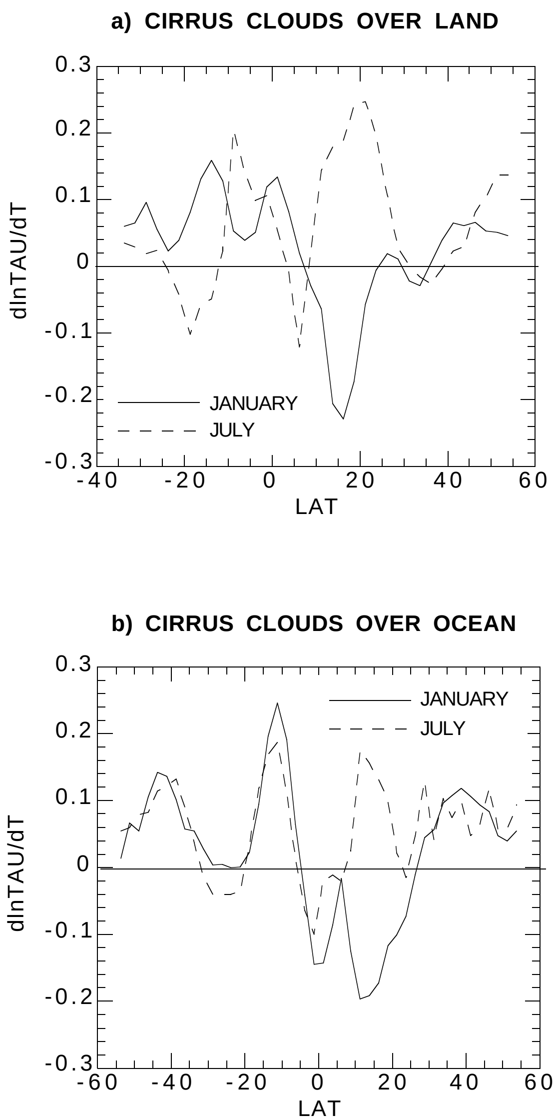

a) CIRRUS CLOUDS OVER LAND
dlnTAU/dT
LAT
JANUARY
JULY
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-40
-20
0
20
40
60
b) CIRRUS CLOUDS OVER OCEAN
dlnTAU/dT
LAT
JANUARY
JULY
-60
-40
-20
0
20
40
60

Figure 4